THE MARS METHANE PLUME OF 2003 WAS CAUSED BY A METEOR STORM FROM COMET C/2007 H2 SKIFF.
M. Fries[1] , P. Conrad[2], and I. L. ten Kate[3], [1]NASA Astromaterials Acquisition and Curation Office, Johnson Space Center, Houston, TX, [2]Geophysical Laboratory, Carnegie Institution for Science, Washington DC, [3]Department of Earth Sciences, Utrecht University, Netherlands. Email: marc.d.fries@nasa.gov

Description: On 11 Jan 2003 a regional "plume" of methane was observed on Mars via Earth-based telescopic observation [1]. An accumulation of lines of evidence has led to the hypothesis that this methane plume arose from an intense meteor shower (or "meteor storm") in the same latitude, a few days previously [2], arising from Mars-crossing comet C/2007 H2 Skiff. The lines of evidence for this hypothesis are as follows:

Mechanism: Meteor showers deliver reduced carbon to Mars' atmosphere and surface [3], and methane is produced readily by UV photolysis of meteoritic carbon [4,5].

Mass: Meteor storms in Mars' vicinity can deliver sufficient mass to generate the methane plume recorded by Mumma et al (2009), as directly measured by Mariner IV which was damaged in the vicinity of Mars' orbit by a cometary debris stream with flux 10,000x greater than the sporadic background [6]. This value was calculated [7] as necessary to generate the methane in [1].

Timing: Mars encountered the orbit of comet C/2007 H2 Skiff for a calculated period of ~28 hours [8] centered around L_S=119.2° [9]. H2 Skiff's activity is unusual, however, in that it is prone to strong meteor outbursts late in the encounter, with predicted activity diminishing ~2.8 days before the Mumma et al methane observation. This closely matches the date calculated for the methane emission by global circulation modeling (Figure 1)[2, 6].

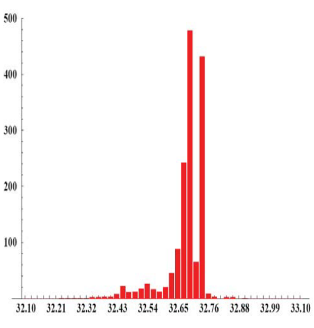

Figure 1: Predicted meteor activity of comet H2 Skiff at Mars, from Christou and Vaubaillon (2011). Strong outbursts appear late in the encounter, ending 2.8 days before the methane plume observation [1].

Orbital Geometry: The orbit of comet H2 Skiff interacted with Mars in an ascending node that passed very close (2.2 lunar distances) from Mars and well within the debris trail predicted by [8]. The declination angle of H2 Skiff (-35.7°) corrected for Mars' axial tilt at L_S=119.2° means the sub-radiant latitude on the red planet was -27.5°. Assuming a meteor storm duration of 1.2 hours [8] and that the storm footprint covered the entire planetary disk visible from the radiant, we can calculate an estimated extent of meteors (concentric ovals in Figure 2). Assigning an H2 Skiff meteor storm the same longitude as the methane plume in [1], the detected methane is accommodated within the meteor storm footprint. Methane dissemination due to global winds was calculated previously [10] and seemed to suggest a mild northward movement of methane, but this model assumed ground-level methane release and should be re-calculated for the high-altitude methane release attendant with a meteor storm.

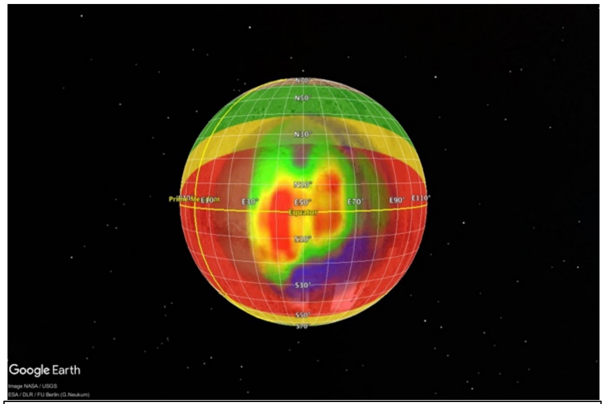

Figure 2: Image of the Mumma et al methane plume [1] superimposed on a calculation of the spatial extent of a meteor storm from C/2007 H2 Skiff (concentric red, yellow, and green) on a Mars globe. Latitude is determined by the geometry of the encounter and longitude is a function of the time of the encounter. (Image credit: Google Earth/Mars).

Comet Suitability: In an independent study, comet H2 Skiff was identified as likely to produce meteor outbursts and as the source of the strongest meteor showers predicted for Mars, the Microscopids [9]. Meteor storm duration data from [6,9] and the sub-radiant latitude from [9] indicate that the expected spatial extent and location of a Microscopid meteor storm coincide with the observed location of the Mumma et al methane plume. Analysis of H2 Skiff's small minimum orbital interaction distance (MOID) with Mars and absolute nucleus magnitude of 19.2 indicates that it is a Potentially Hazardous Object (PHO) for Mars. H2 Skiff features significant orbital perturbations, with its orbit crossing Mars' orbit twice in the past nine years.

Data Favors Methane from Above: Furthermore, delivery of carbon via meteor infall – as opposed to an underground source – provides a methane destruction rate from high-altitude UV photolysis that better explains the observed, rapid decline of methane concentration that is a poor match for expected surface-level chemistry [11, see discussion in 2]. Furthermore, it is reasonable to expect that the large gas volume involved in martian methane plumes would have produced a significant surface disruption and albedo change due to co-release of dust and debris. Such a signature features disruption and dust movement similar to a fresh impact crater, but may be considerably larger. To date, while over 900 meteorite impact scars have been seen to appear on Mars [12], most if not all of which displaced less material than the volume of gas involved in [1], *not a single report* exists for detection of surface disruption from underground methane release in orbital imagery. Gas release from an underground source is not supported by the very large data set of orbital imagery available to date, and is most likely not an active process on Mars today. By contrast, meteor showers are known to occur [3], it is reasonable to accept that they deliver reduced carbon to the martian surface and atmosphere [13], and they generate methane via a well-established mechanism [4,5]. Therefore methane arising from extraterrestrial infall is favored over an underground source.

Summary: Our initial search for a potential cometary encounter related to the Mumma et al (2009) methane plume was based solely on finding a close match to the timing of the methane detection. That search produced comet C/2007 H2 Skiff. H2 Skiff turns out to be:

- a Potentially Hazardous Object (PHO) for Mars prone to strong meteor outbursts,
- whose orbital geometry produces meteor showers at a latitude conducive to the Mumma et al methane,
- with a spatial distribution that is a reasonable match for the observed methane,
- with methane generated via a Mars-relevant mechanism that has been confirmed in multiple laboratories.

Also,

- the total meteor mass required [7] for [1] has already been seen to occur in a near-martian orbit [6], and
- the spatial extent and sudden input of reduced carbon from a meteor storm is a precise match to the necessary conditions Mischna et al (2011) identified as the starting conditions for the Mumma et al plume. Namely, "*the shape and magnitude of the observed methane distribution requires invocation of a large initial source region*" and "*must have been derived from a near instantaneous release event rather than a slow, steady emission*" [10]. This description closely matches the spatial and temporal conditions for a meteor storm from comet C/2007 H2 Skiff. Mischna et al also found that their model could not reconcile an underground source emanating from a point locality with the methane distribution seen in [1].

In summary, we find a robust causative link between a meteor storm from comet H2 Skiff and Mumma et al's observation of a methane plume. In the larger picture, this finding is very important for the search for potential life on Mars because it is reasonable to expect multiple sources for methane on Mars, and characterizing abiogenic methane sources is a critical step in the search for potential biological signatures.

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